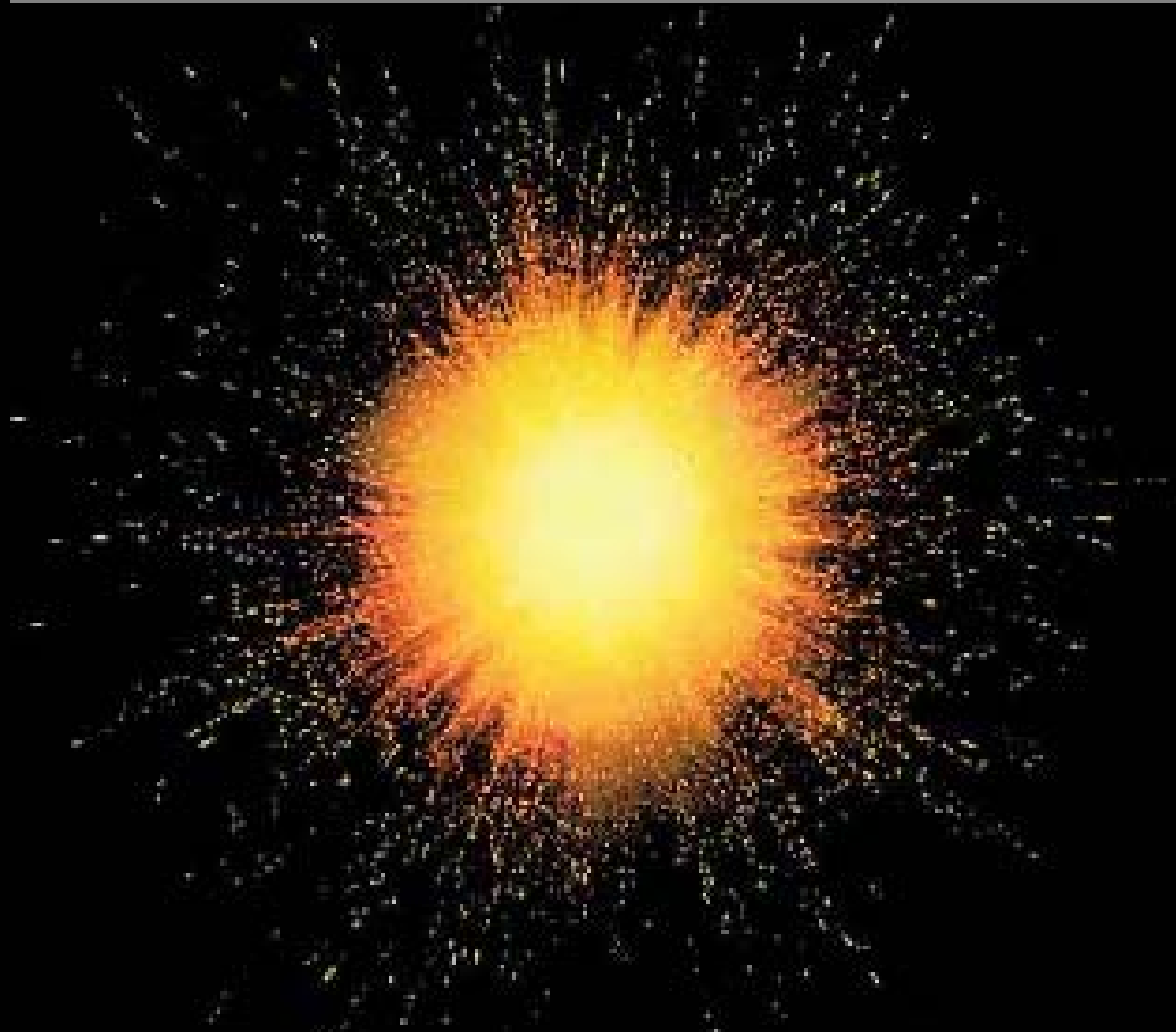
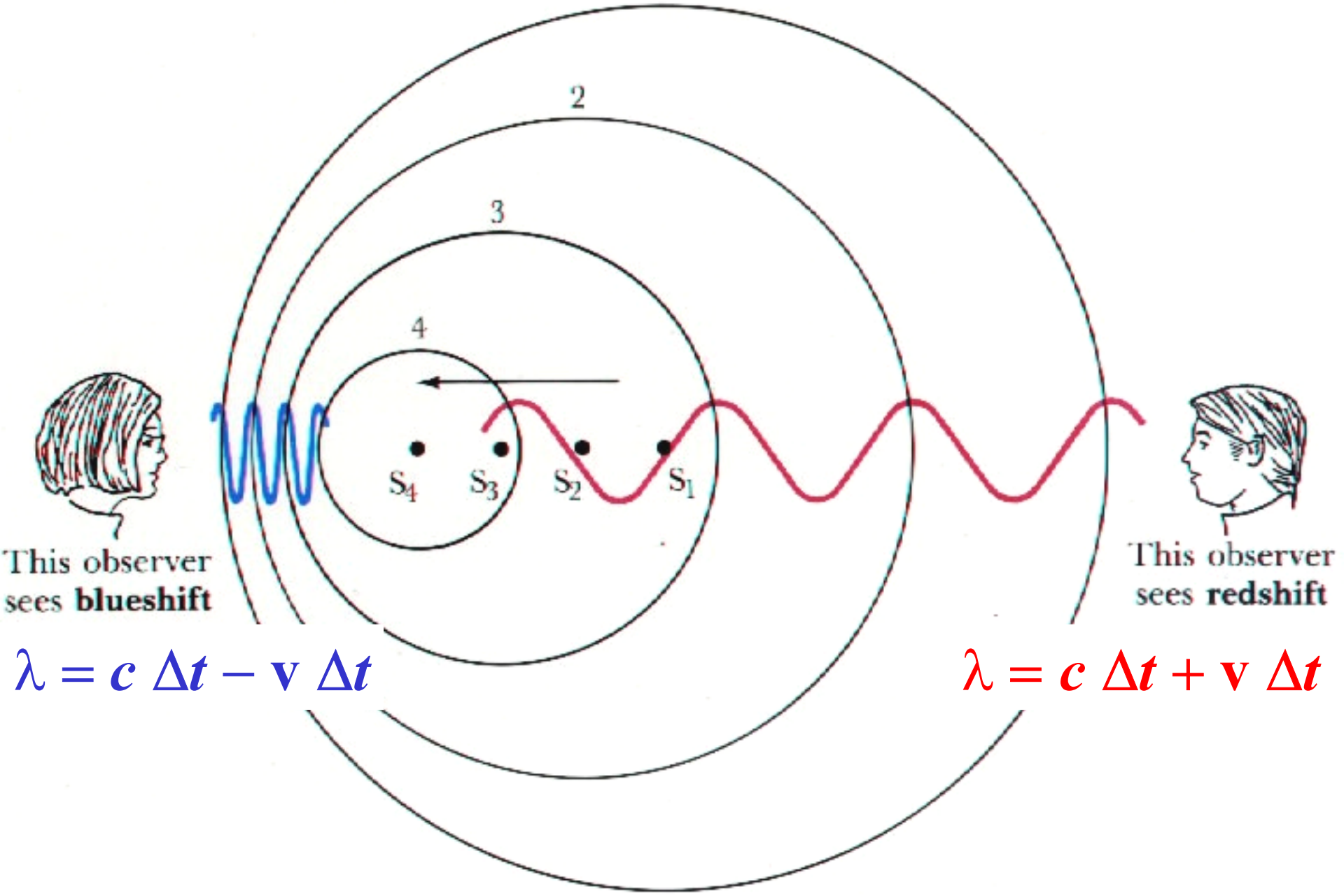
This is not the big bang!



Models Lecture 7


2
3
4
S_4
S_3
S_2
S_1
This observer sees **blueshift**
This observer sees **redshift**
$\lambda = c\,\Delta t - v\,\Delta t$
$\lambda = c\,\Delta t + v\,\Delta t$

Doppler Shift

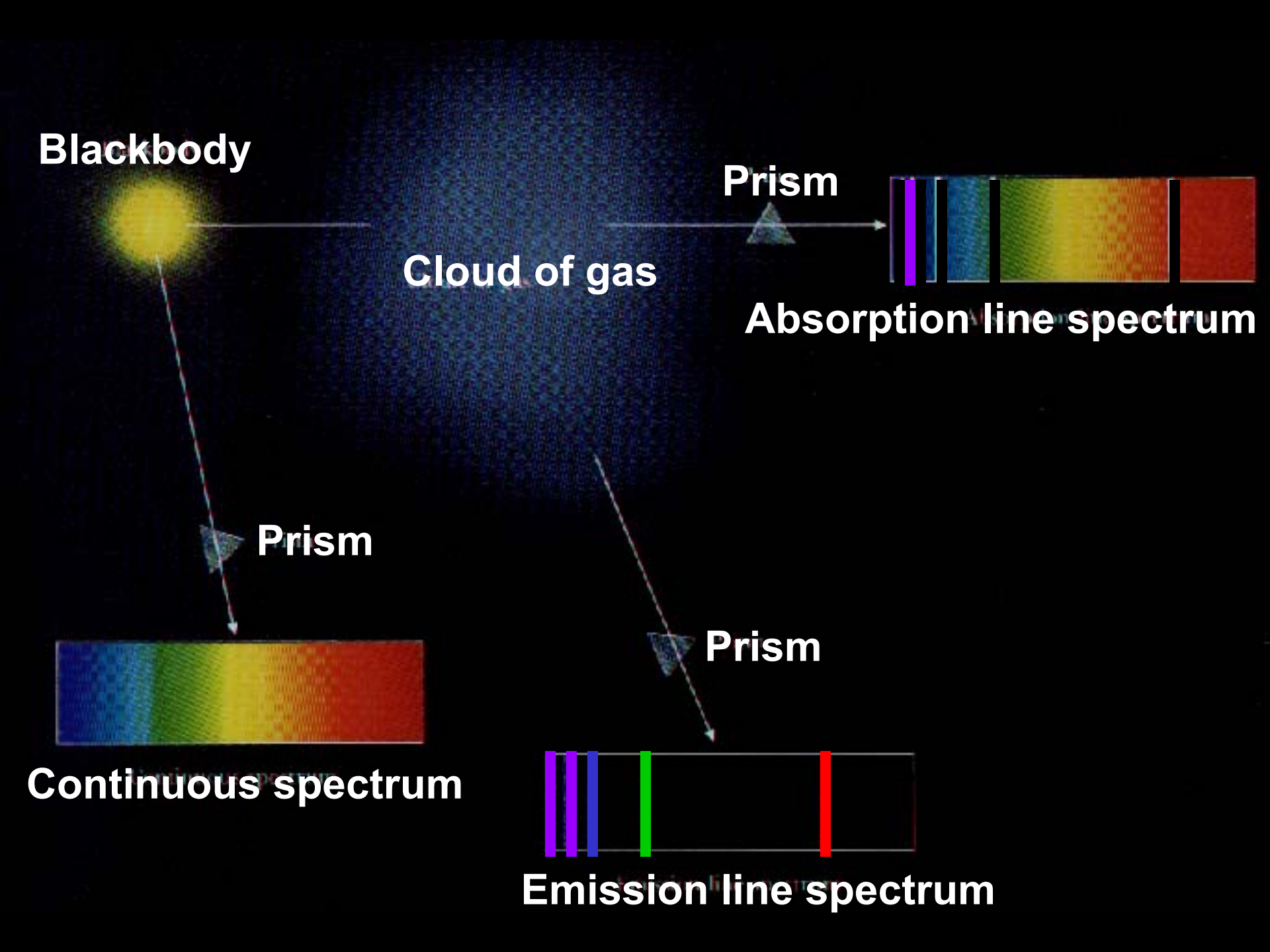
$\lambda_0 =$ rest wavelength

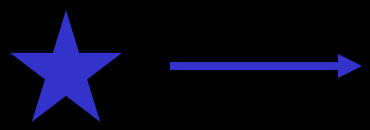
$\lambda =$ detected wavelength

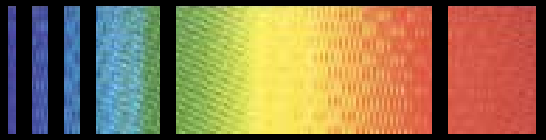
$$\lambda = \lambda_0 \left(1 \pm \frac{v}{c} \right)$$

$+ \rightarrow$ receding (longer λ)

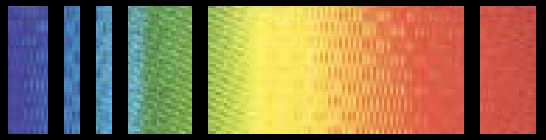
$- \rightarrow$ approaching (shorter λ)

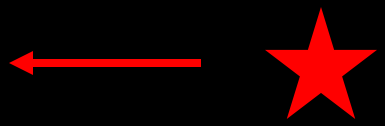

Blackbody
Prism
Cloud of gas
Absorption line spectrum
Prism
Prism
Continuous spectrum
Emission line spectrum

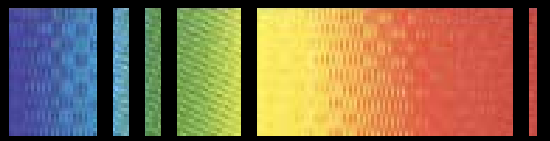




blue shift



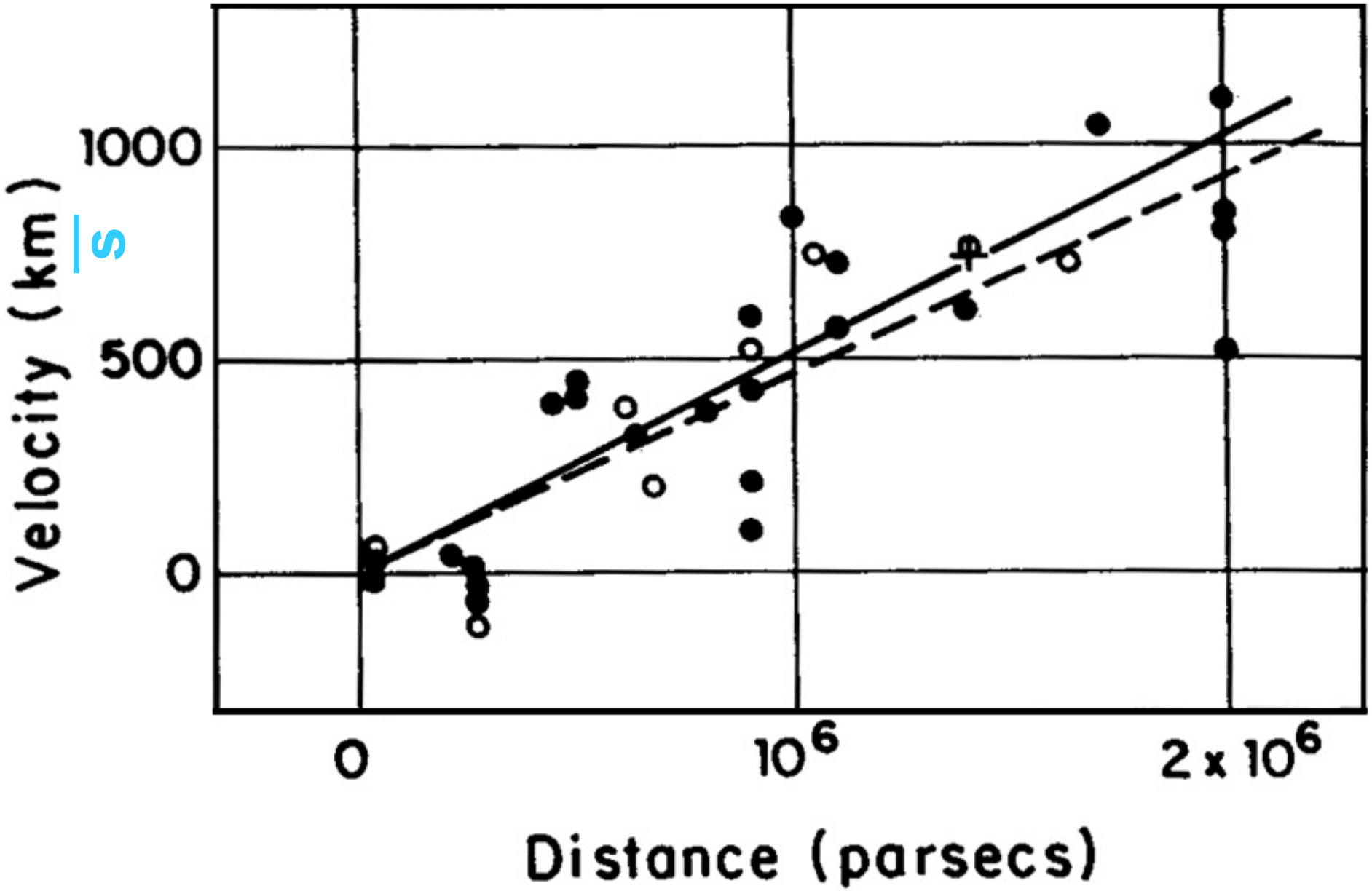




red shift

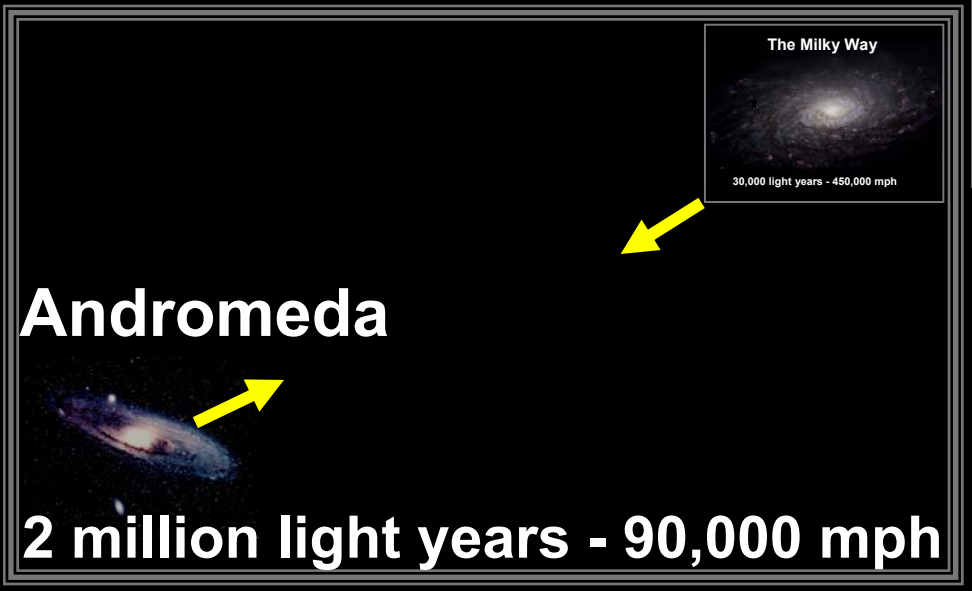
Edwin Hubble
1884 - 1953

Hubble's Discovery Paper - 1929



Arrangement

Arrangement

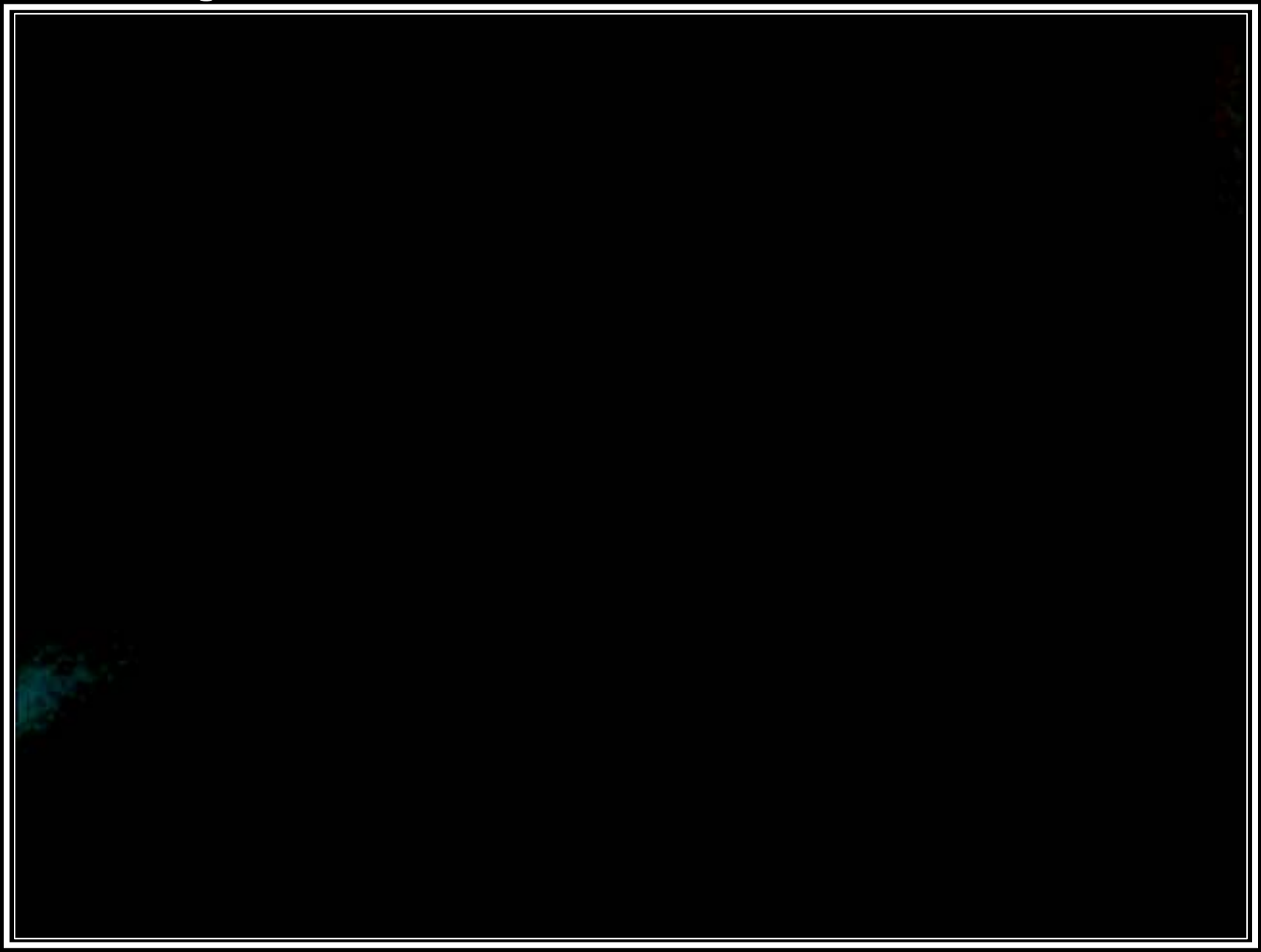


blueshift = 300 km s^{-1}
distance = 0.65 Mpc

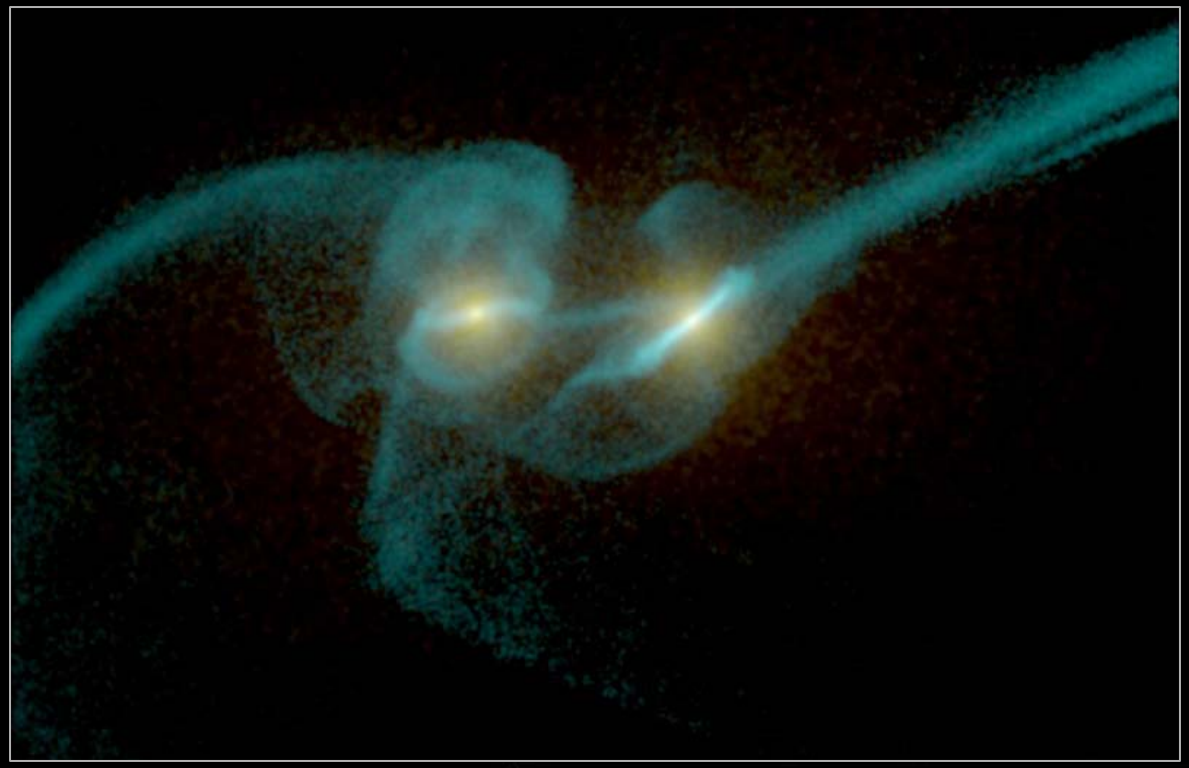
$$300\frac{\text{km}}{\text{sec}}\times\frac{3\times10^{7}\text{sec}}{\text{yr}}\times\frac{1\text{Mpc}}{3\times10^{19}\text{km}}$$

$$=\frac{1\text{ Mpc}}{3\text{ Gyr}}\Rightarrow 0.65\text{ Mpc in 2 Gyr}$$

When galaxies collide: Joshua E. Barnes & John E. Hibbard

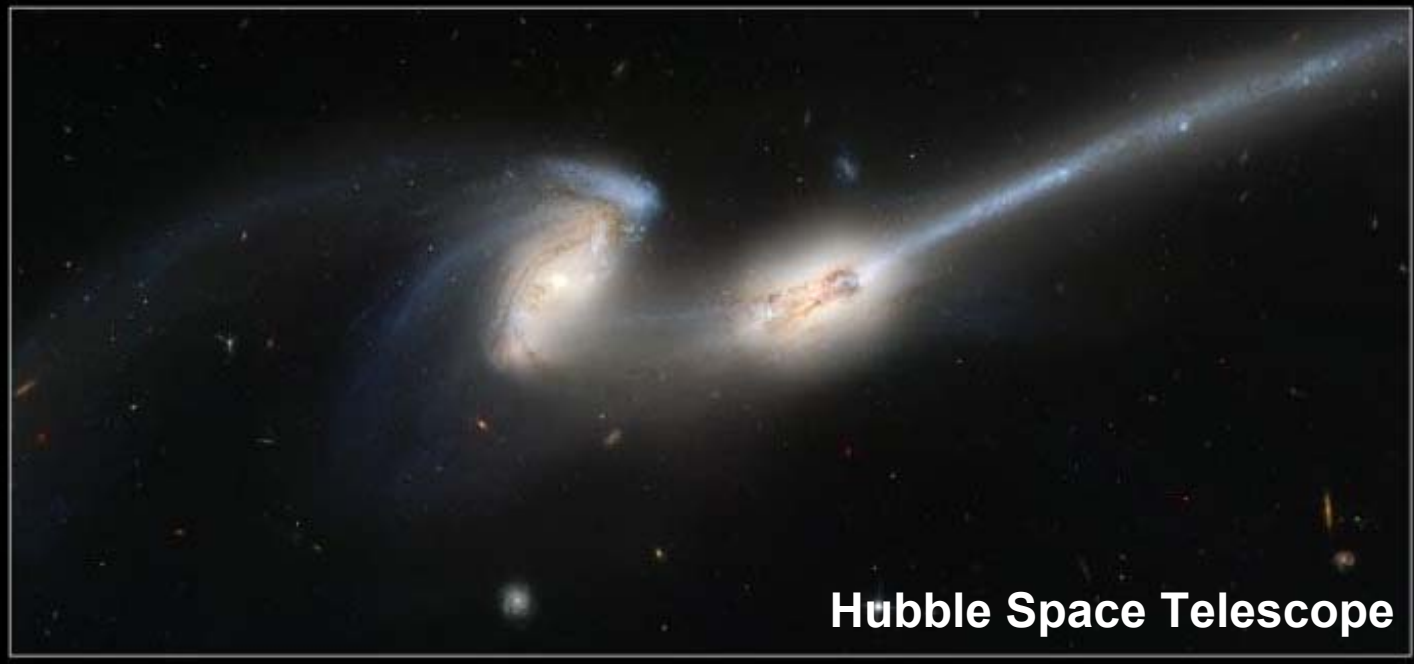


Every second equivalent to 100 million years



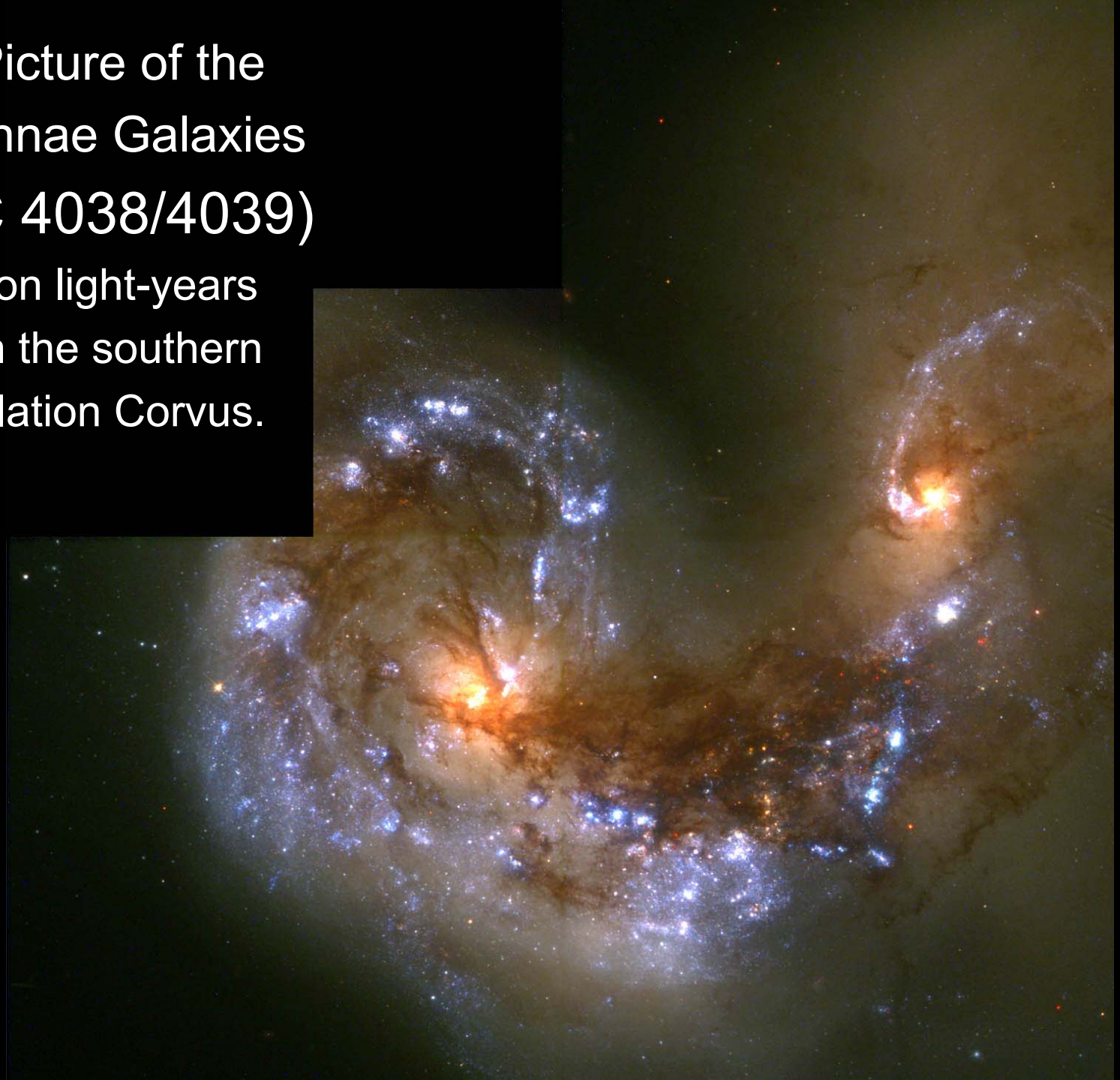
Barnes & Hibbard simulation

“The Mice” Galaxies



HST Picture of the Antennnae Galaxies (NGC 4038/4039)

63 million light-years away in the southern constellation Corvus.



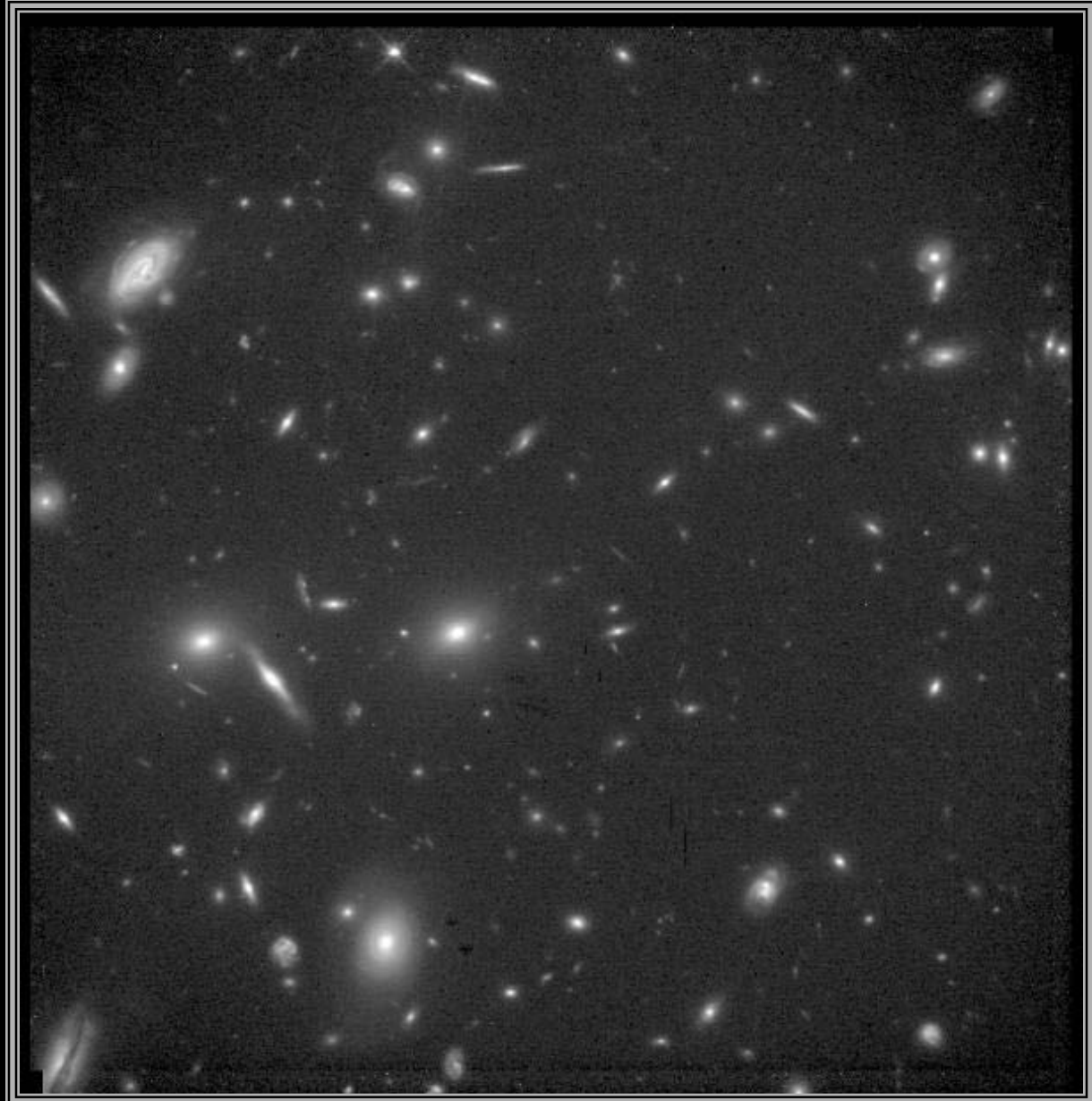
Mergers and Acquisitions

each second is 300 million years

Matthias Steinmetz
Max Planck Institute

Arrangement

Cluster
of
Galaxies



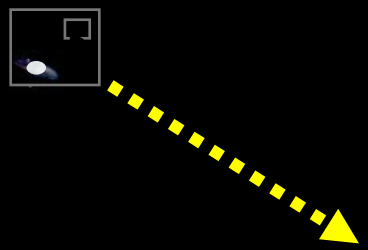
Arrangement

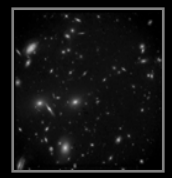
The Milky Way

30,000 light years - 450,000 mph

Andromeda

2 million light years - 90,000 mph



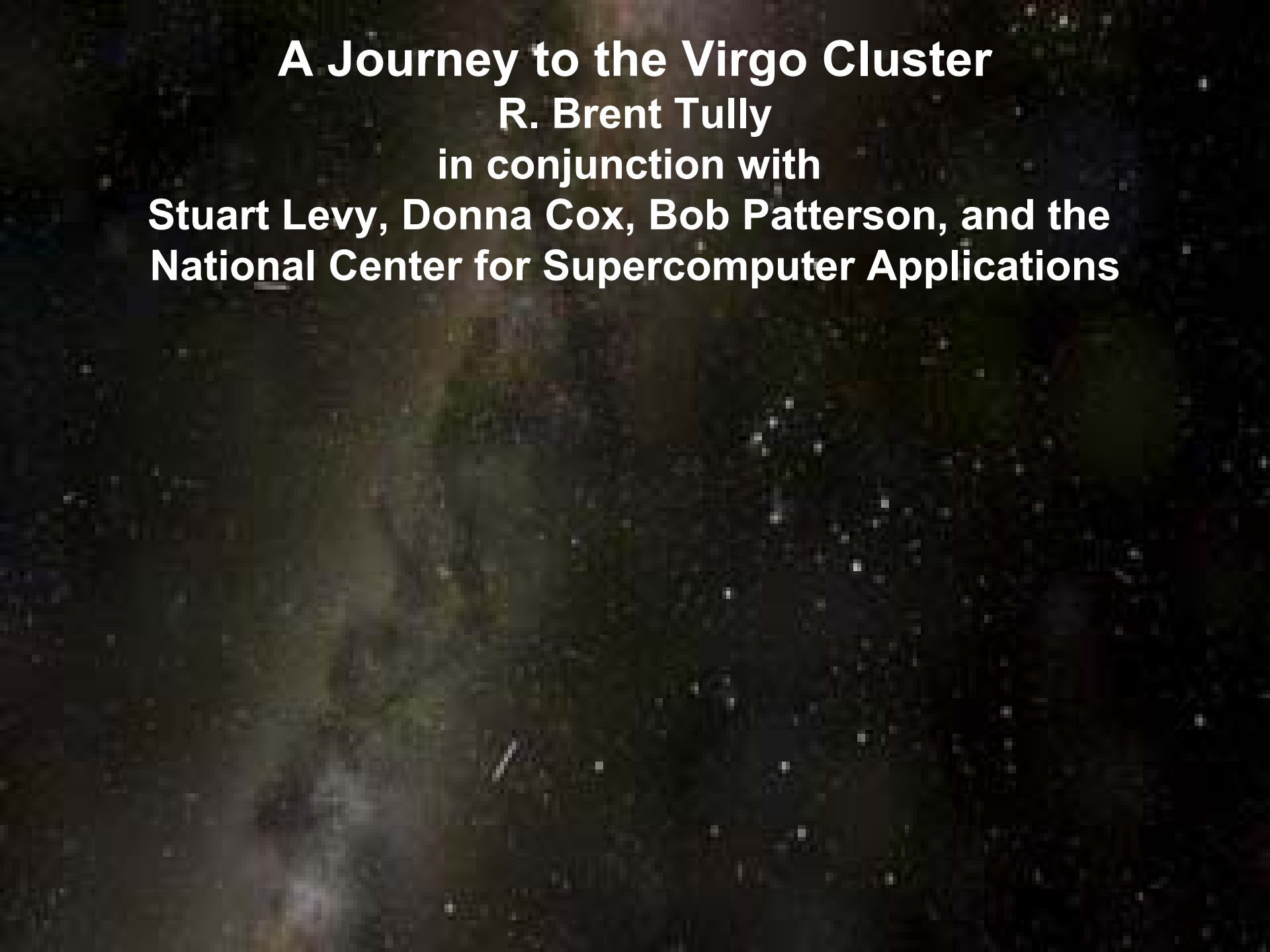


Virgo cluster

50 million light years - 7,500 mph

A Journey to the Virgo Cluster

R. Brent Tully
in conjunction with
Stuart Levy, Donna Cox, Bob Patterson, and the
National Center for Supercomputer Applications




DANGER:
BLACK HOLE
(artist's drawing)

Arrangement

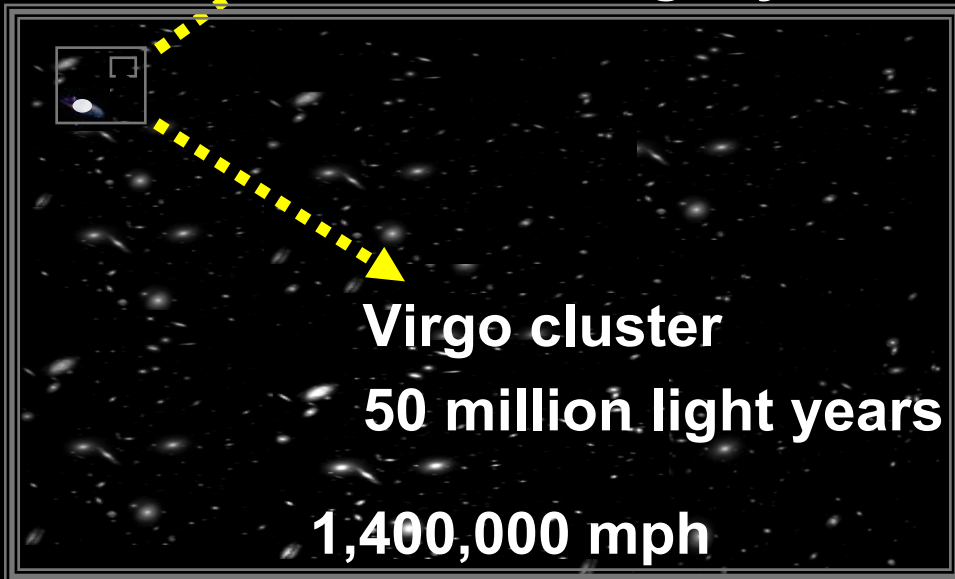
The Milky Way

30,000 light years - 450,000 mph

Andromeda

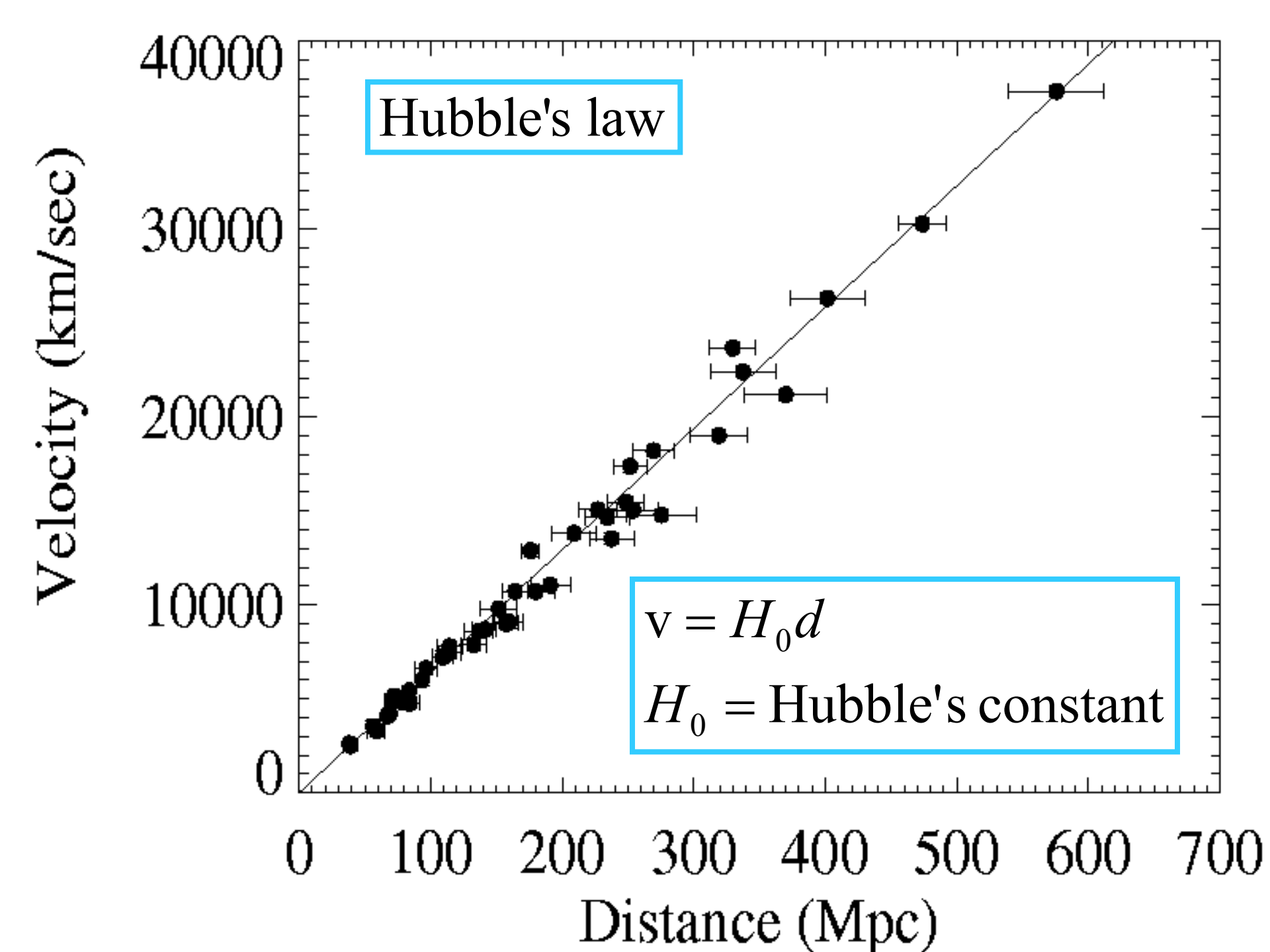
2 million light years - 90,000 mph

Hydra Supercluster
500 million light years



Virgo cluster
50 million light years

1,400,000 mph


Hubble's law
$v = H_0 d$
H_0 = Hubble's constant
Velocity (km/sec)
40000
30000
20000
10000
0
0
100
200
300
400
500
600
700
Distance (Mpc)

Space and Time

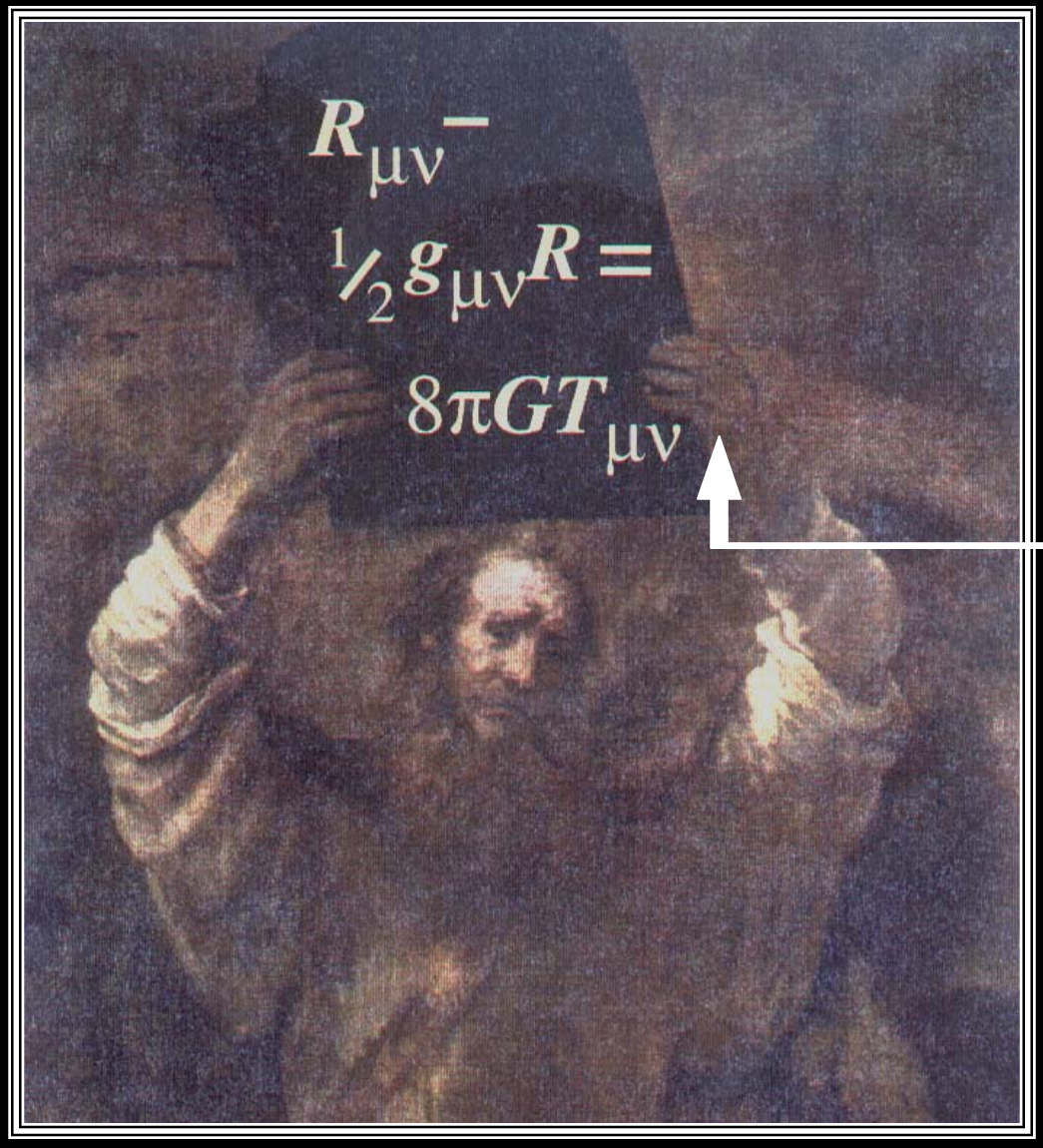
Space and time are related.

Albert Einstein, 1905

Space is dynamical
(curved, warped, bent).

Albert Einstein, 1915

Origin: Modern Laws of Genesis



(10 nonlinear partial differential equations)

Einstein's Cosmic Legacy

The universe is comprehensible!!!

- **Gravity = Geometry**
- **A big-bang origin**
- **A cosmological term (or dark energy)**

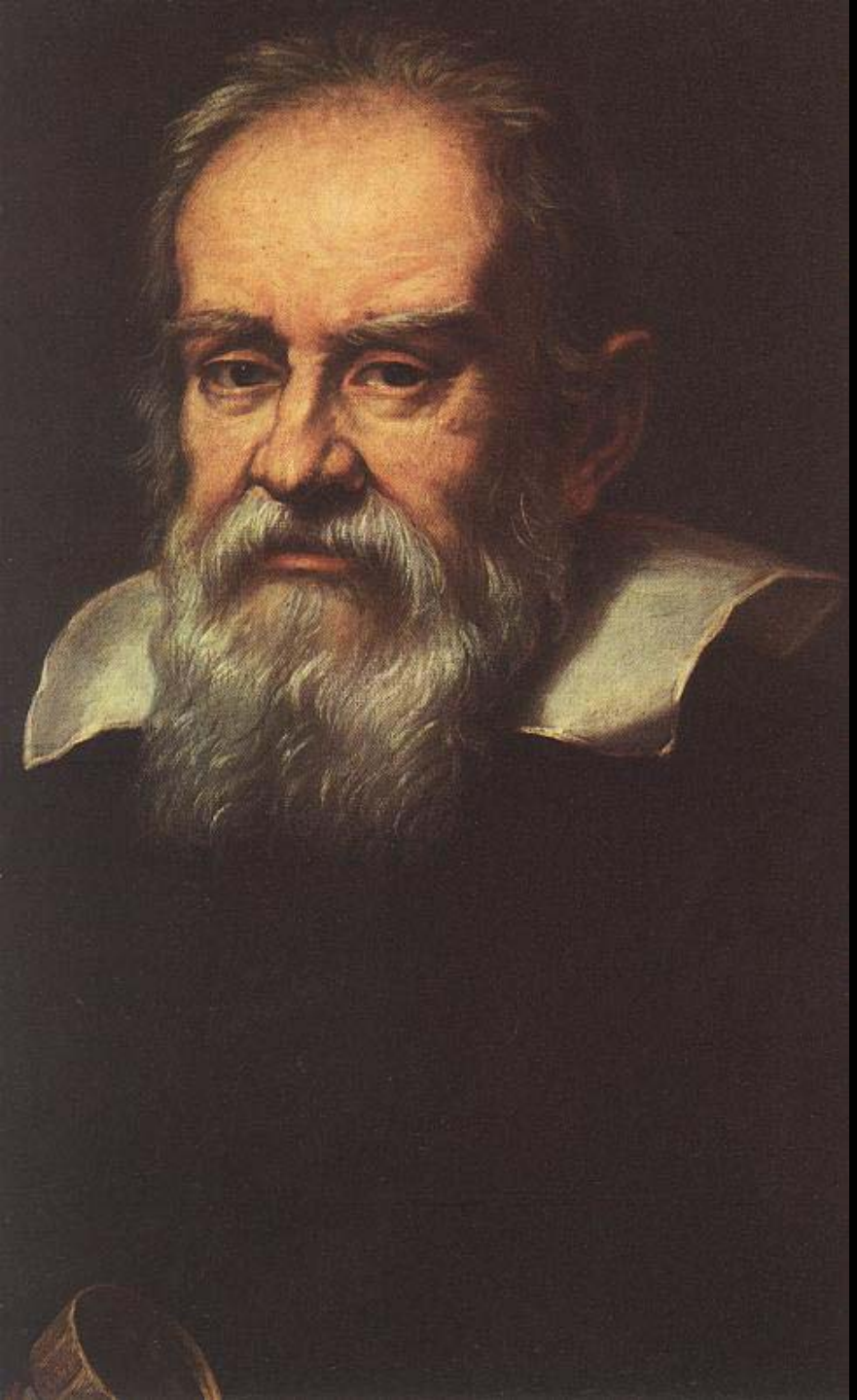
We are not the center of the expansion of the universe

Every galaxy sees the expansion

Cosmological Principle

The universe is the same everywhere

- no special point in the universe (no center)
- no special set of points (no edge)



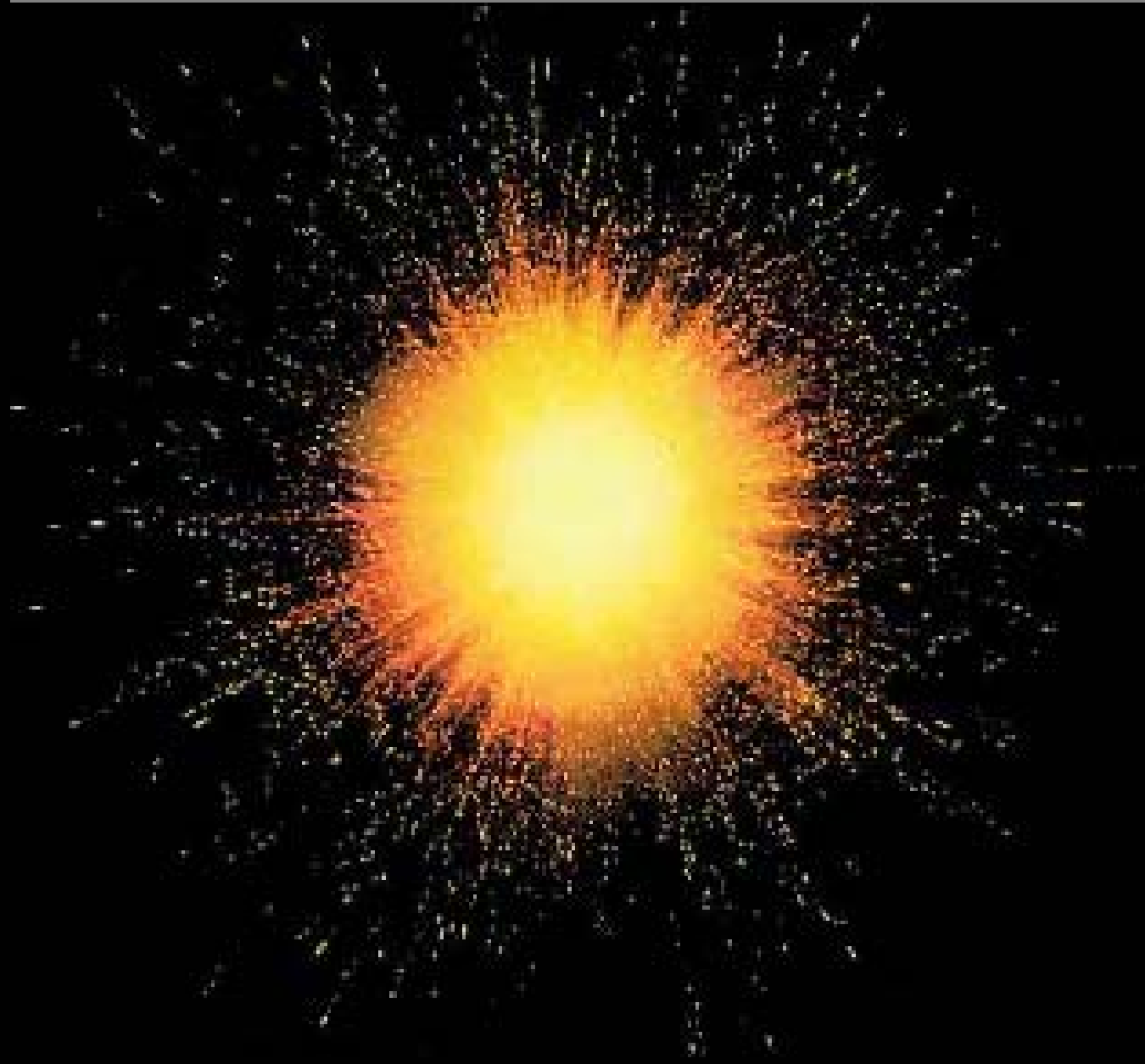
Galileo on the center of the universe, from *Dialog Concerning the Two Chief World Systems*

SALVIATI: ***Ancorché molto ragionevolmente io potessi mettervi in controversia…*** I might very reasonably dispute whether there is in nature such a center, seeing that neither you nor anyone else has so far proved whether the universe is finite and has a shape, or whether it is infinite and unbounded. …But I shall concede to you for the time being that the universe is finite, spherical, and has a center.

In the field of modern cosmology, the first principle is called the “Cosmological Principle. It states that the universe has no center, that it has the same properties throughout. Every place in the universe has, in this sense, equal rights. How can the human race, which has evolved in a universe of such fundamental equality, fail to strive for a society without violence and terror? How can we fail to build a world in which the rights of every human from birth are respected?

Fang Li Zhi
Acceptance speech
for the
Robert F. Kennedy
Memorial Human
Rights Award

This is not the big bang!

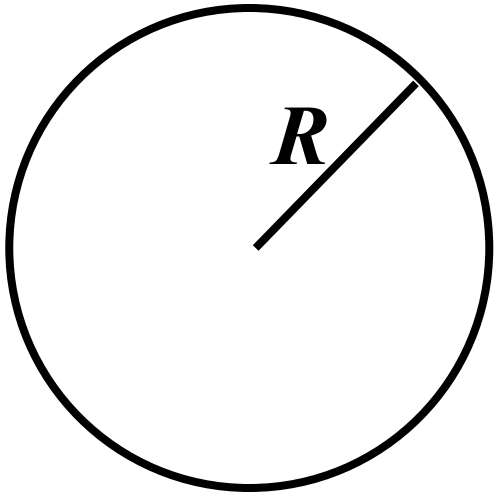


Spaces that obey the cosmological principle:

1-dimension:

^1R  x

$$V = \infty$$

^1S 

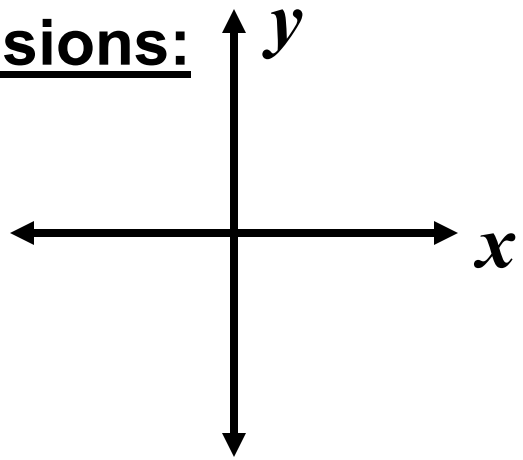
$$V = 2\pi R$$

$$x^2 + y^2 = R^2$$

Spaces that obey the cosmological principle:

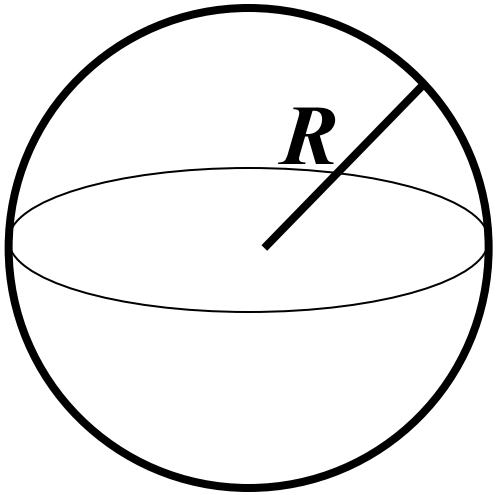
2-dimensions:

^2R



$V = \infty$

^2S

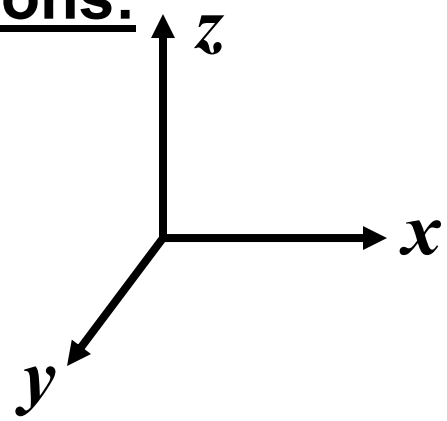


$V = 4\pi R^2$

$$x^2 + y^2 + z^2 = R^2$$

Spaces that obey the cosmological principle:

3-dimensions:



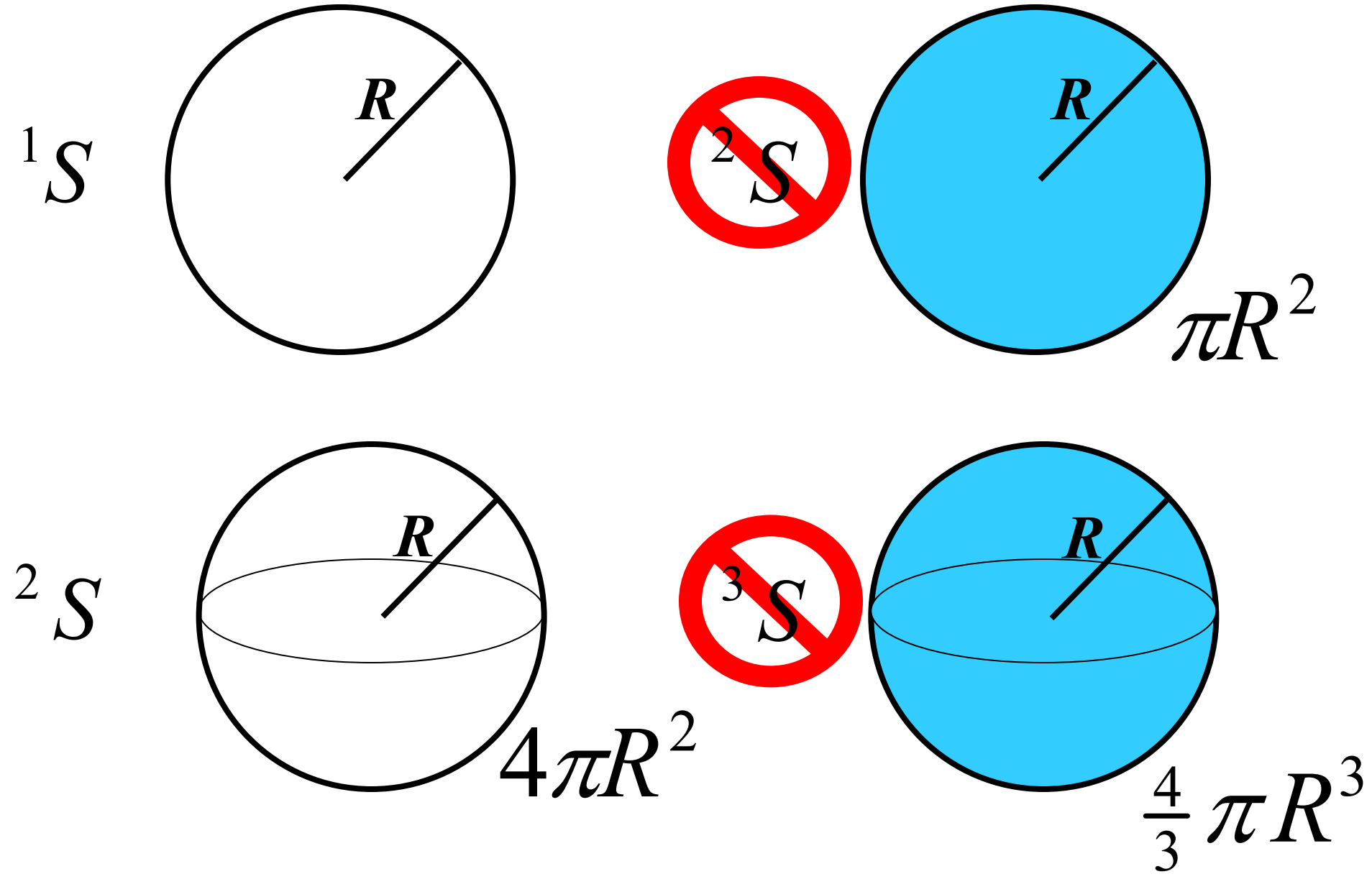
^3R

$$V = \infty$$

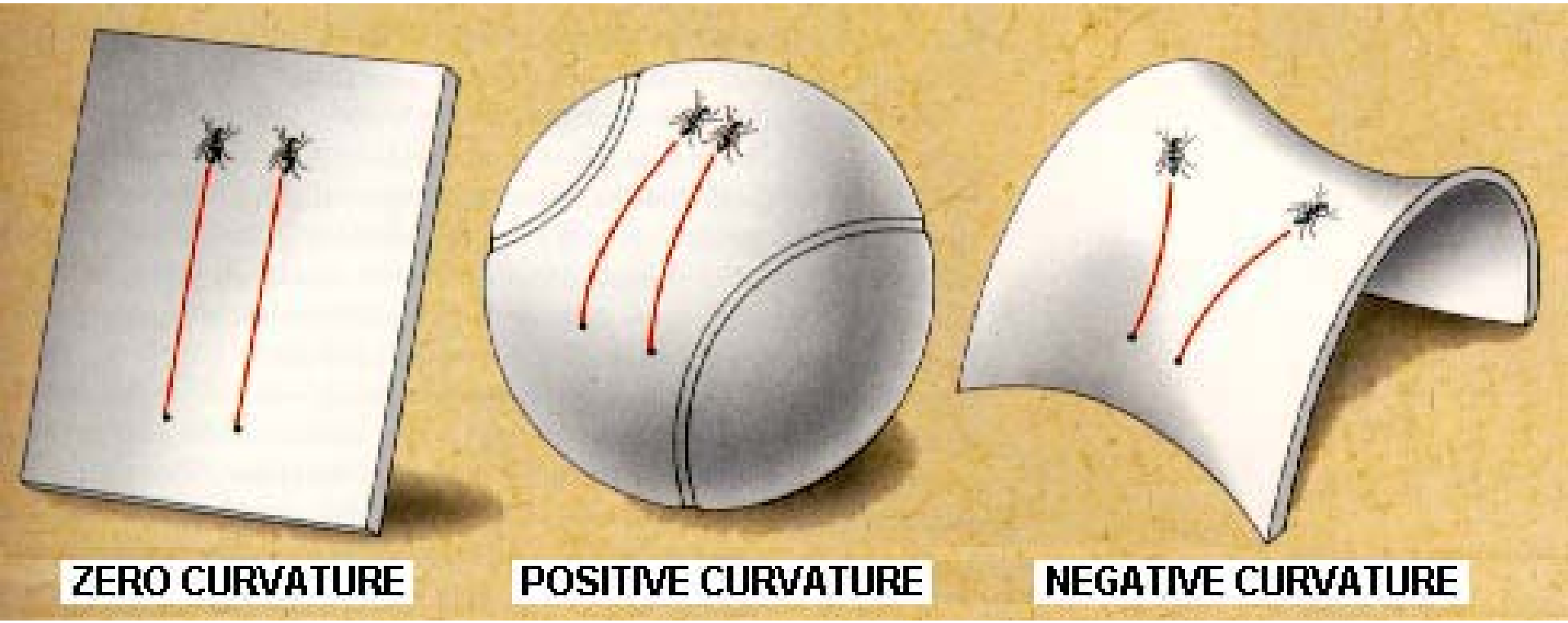
^3S

$$V = 2\pi^2 R^3$$

$$x^2 + y^2 + z^2 + w^2 = R^2$$


^1S
R
^2S
R
πR^2
^2S
R
$4\pi R^2$
^3S
R
$\frac{4}{3}\pi R^3$

^3R ^3S ^3H



FLAT **SPHERICAL** **HYPERBOLIC**

The expansion of the universe is

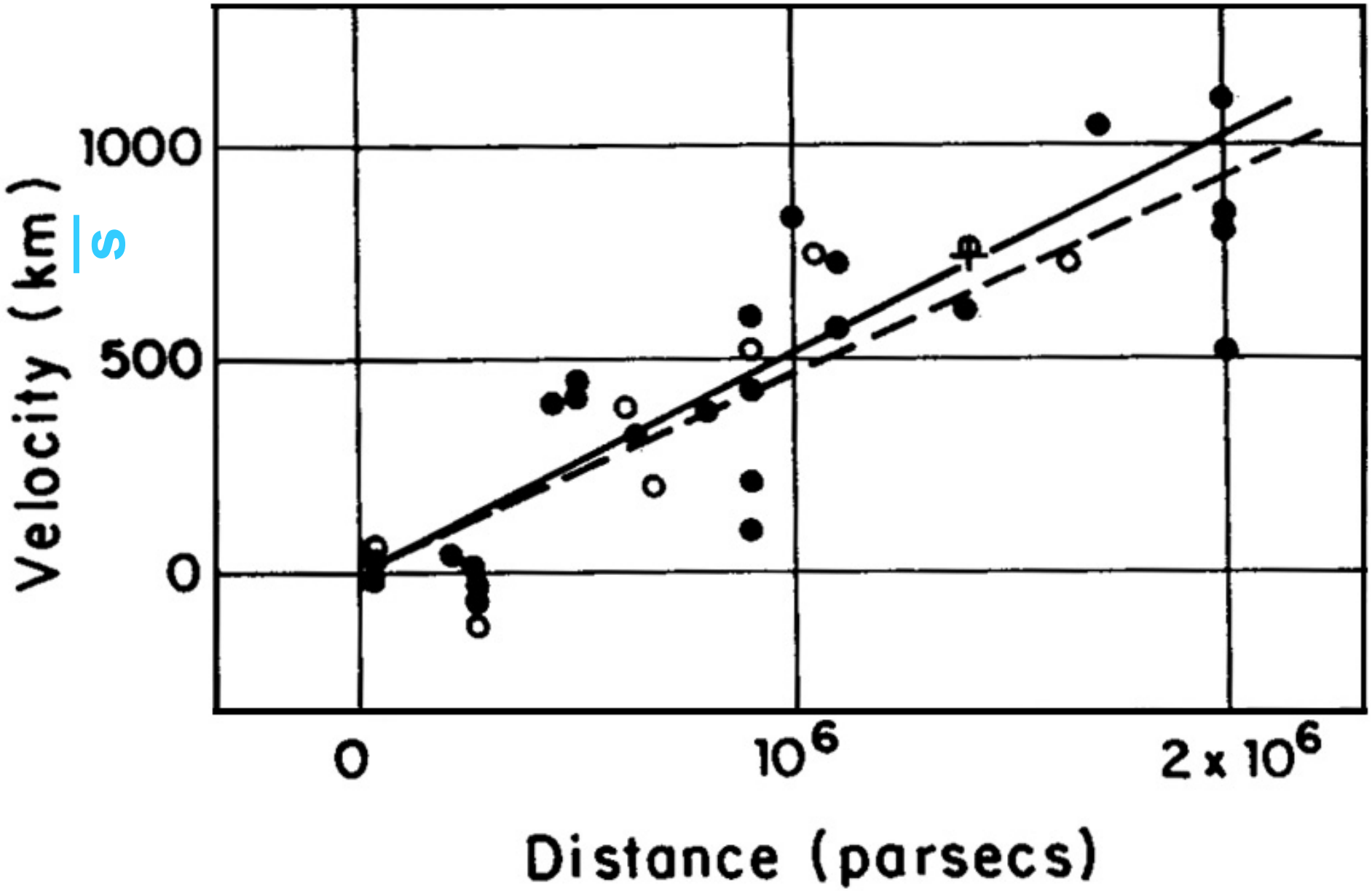
an explosion *of* space

not

an explosion *into* space

The universe does not expand *into* anything!

Hubble's Discovery Paper - 1929



blueshift = 300 km s^{-1}
distance = 0.65 Mpc

A blue shift for nearby galaxies?

We are not the center of the expansion of the universe

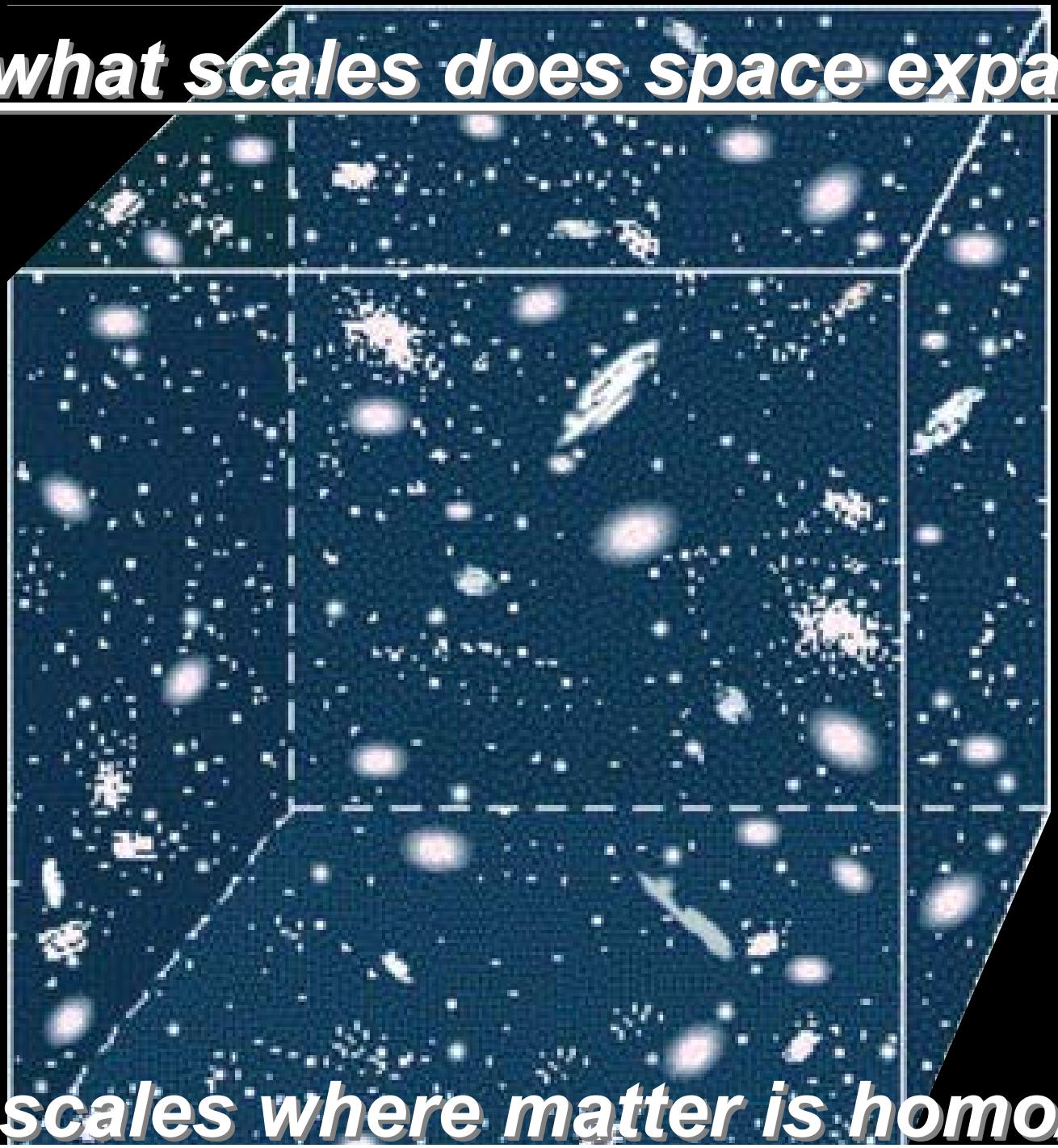
Every galaxy sees the expansion

Cosmological Principle

The universe is the same everywhere

- no special point in the universe (no center)
- no special set of points (no edge)

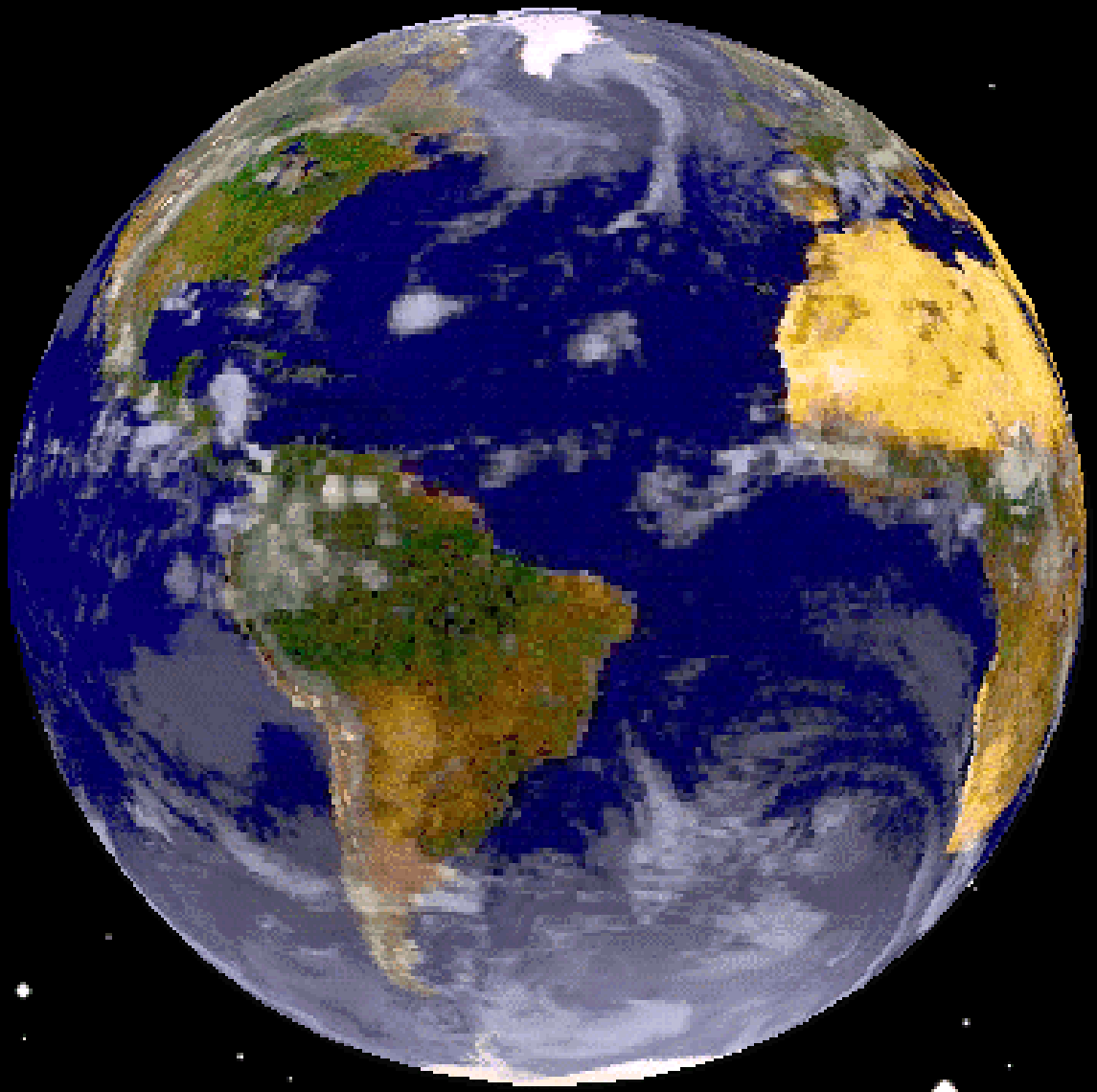
On what scales does space expand?

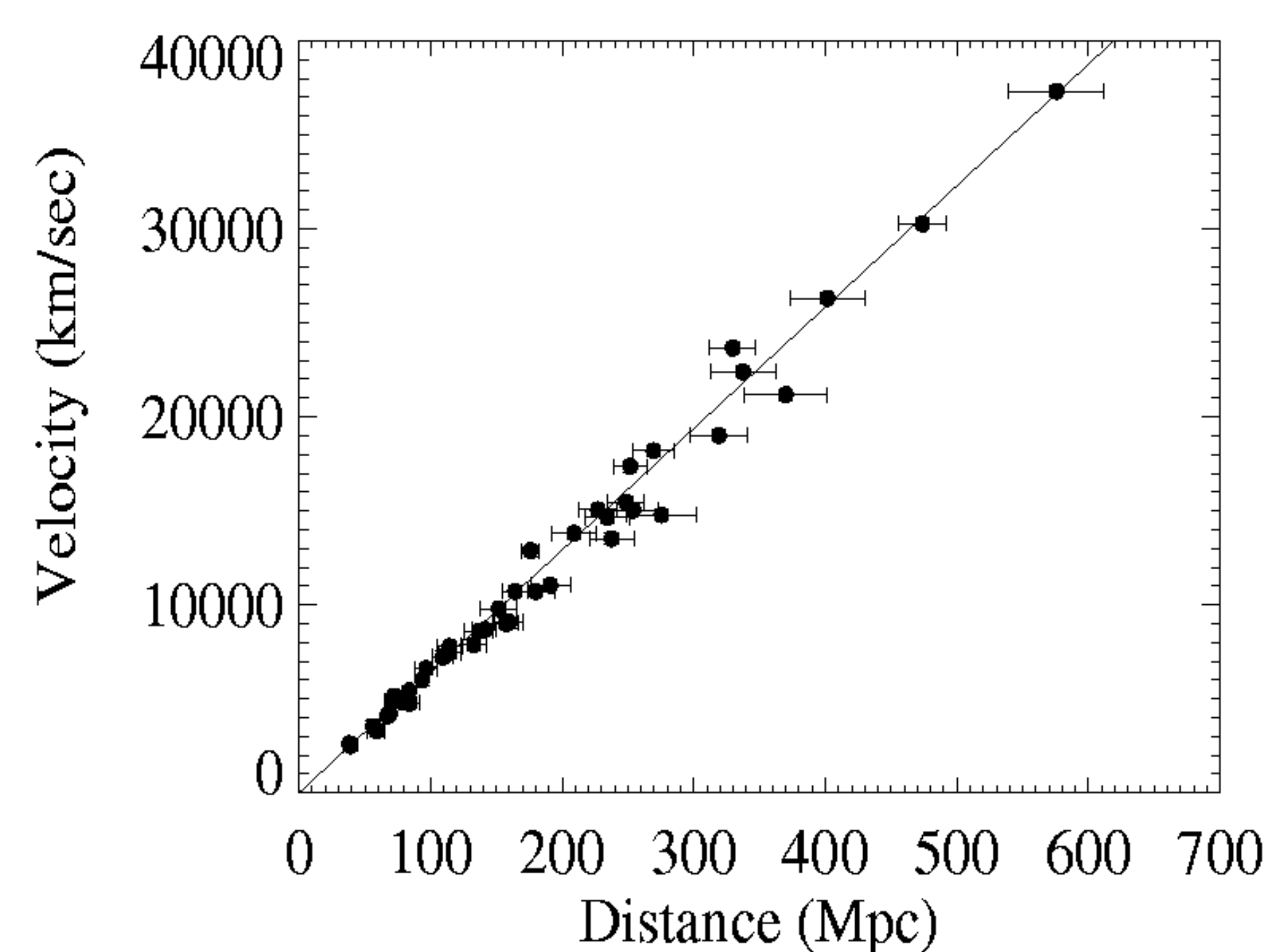


On scales where matter is homo/iso

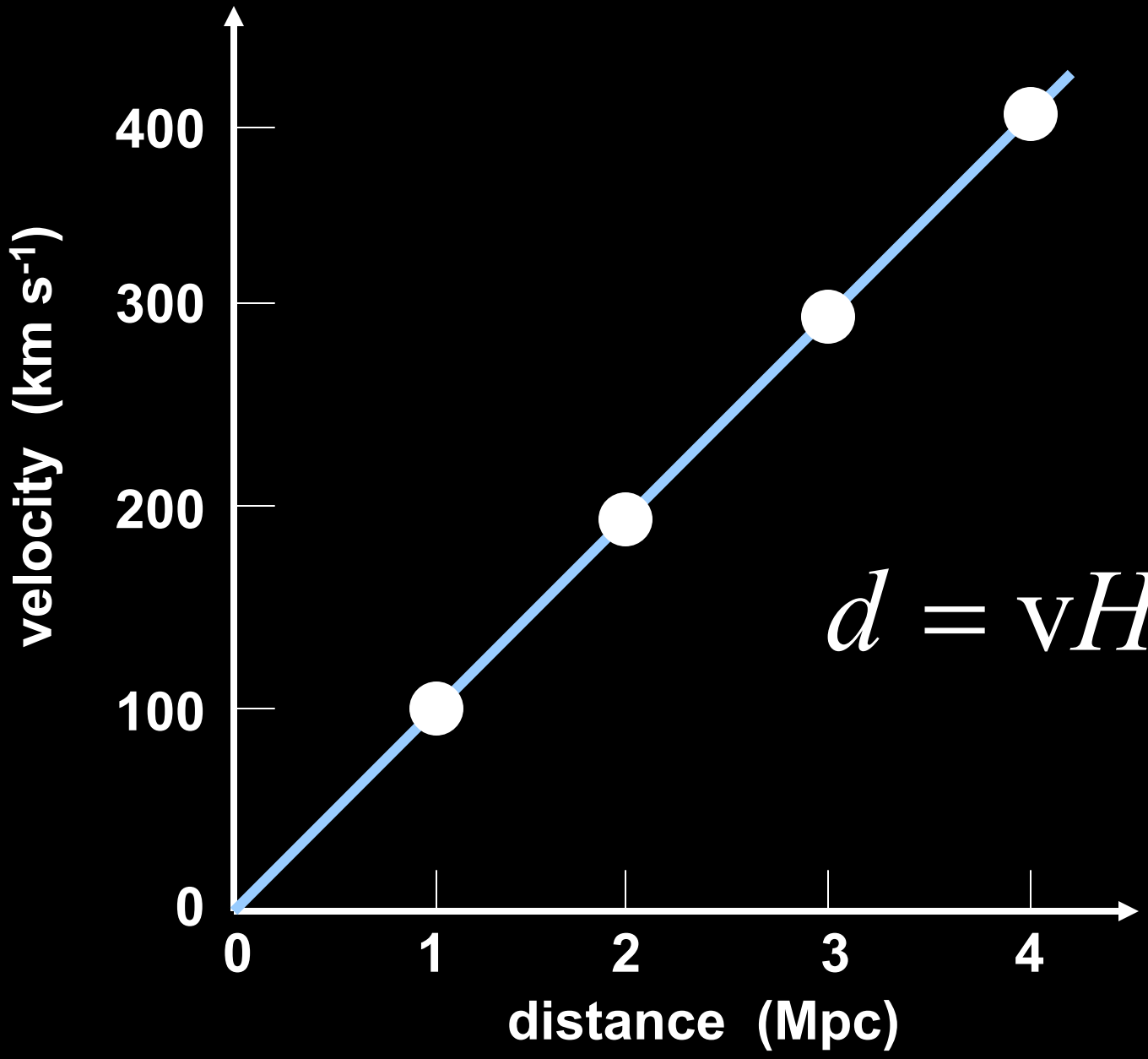

No net gravitational force…
space experiences
“homogeneity & isotropy”

It ain't homo/iso around here!




40000
30000
20000
10000
0
Velocity (km/sec)
0
100
200
300
400
500
600
700
Distance (Mpc)

Hubble's Law: $v = H_0 d$ $(H_0 = 100h$ km s^{-1} Mpc$^{-1})$



The Hubble age of the universe

$$d = vt \qquad \text{distance} = \text{velocity} \times \text{time}$$

$$d = vH_0^{-1} \quad \text{Hubble's law}$$

$$\Big\} \; t = H_0^{-1}$$

$$H_0 = 100h \ \text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1} \times \frac{1\ \text{Mpc}}{3\times10^{19}\ \text{km}}$$

$$(0.8 \geq h \geq 0.6)$$

$$= \frac{100h}{3\times10^{19}}\,\text{s}^{-1} \times \frac{3\times10^{7}\ \text{s}}{1\ \text{year}}$$

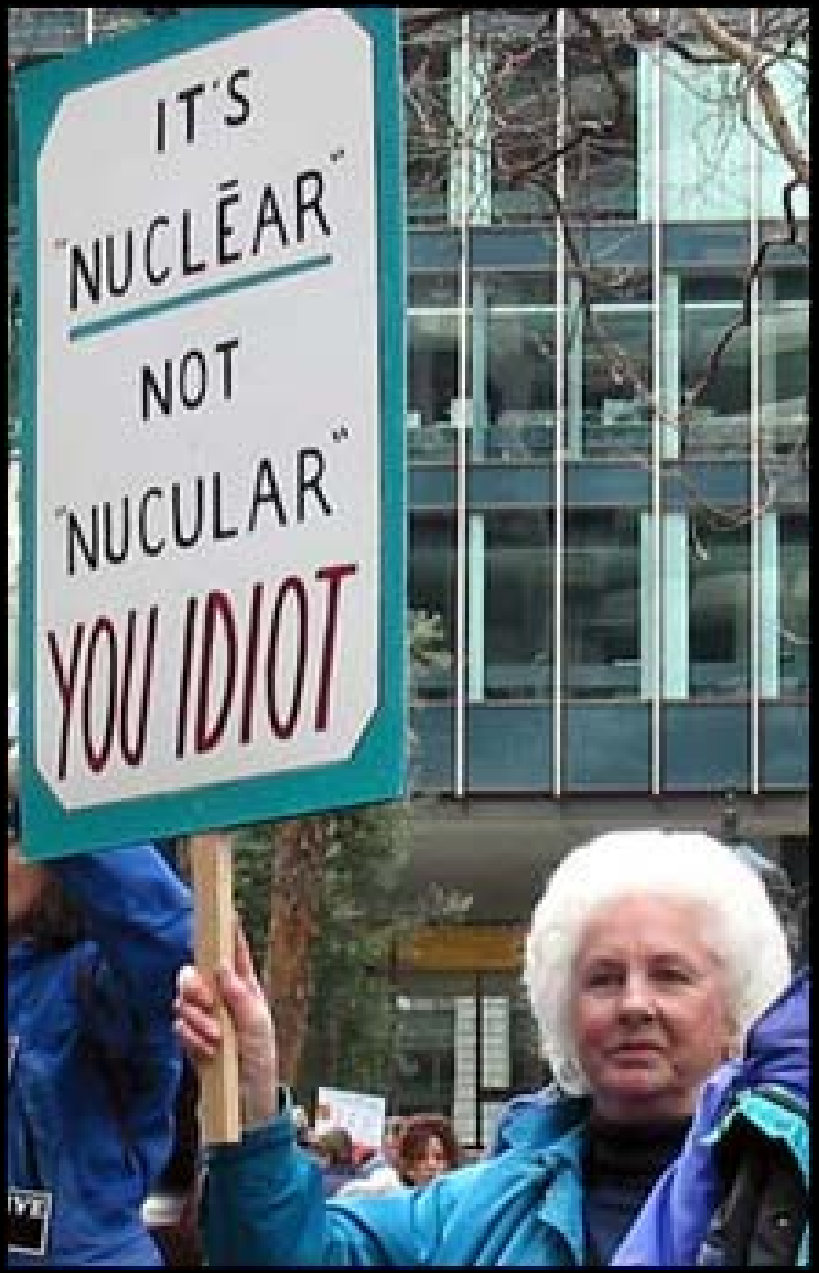
$$= \frac{100h}{10^{12}\ \text{years}} = \frac{h}{10^{10}\ \text{years}}$$

$$t = 10^{10}\,h^{-1}\ \text{years}$$

$$12.5 \leq t \leq 17\ \text{Gyr}$$

$$1\ \text{Gyr} = 10^{9}\ \text{years}$$

Nuclear Physics

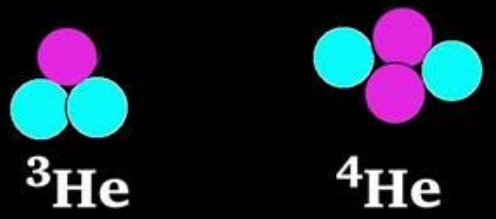


Nucleus made of

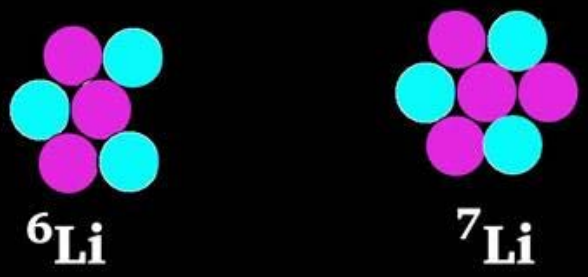
- protons – charge = +1
- neutrons – charge = 0

Hydrogen
1 proton

Helium
2 protons



Lithium
3 protons



The age of the elements

- Elements come in different isotopes
  (same # of protons, different number of neutrons)
- Many isotopes are radioactive — they decay
- If start with $N(0)$ nuclei, after a time *t*, the number will be

$$N(t) = N(0)\, 2^{-t/\tau_{1/2}}$$

$\tau_{1/2}$ is the half-life

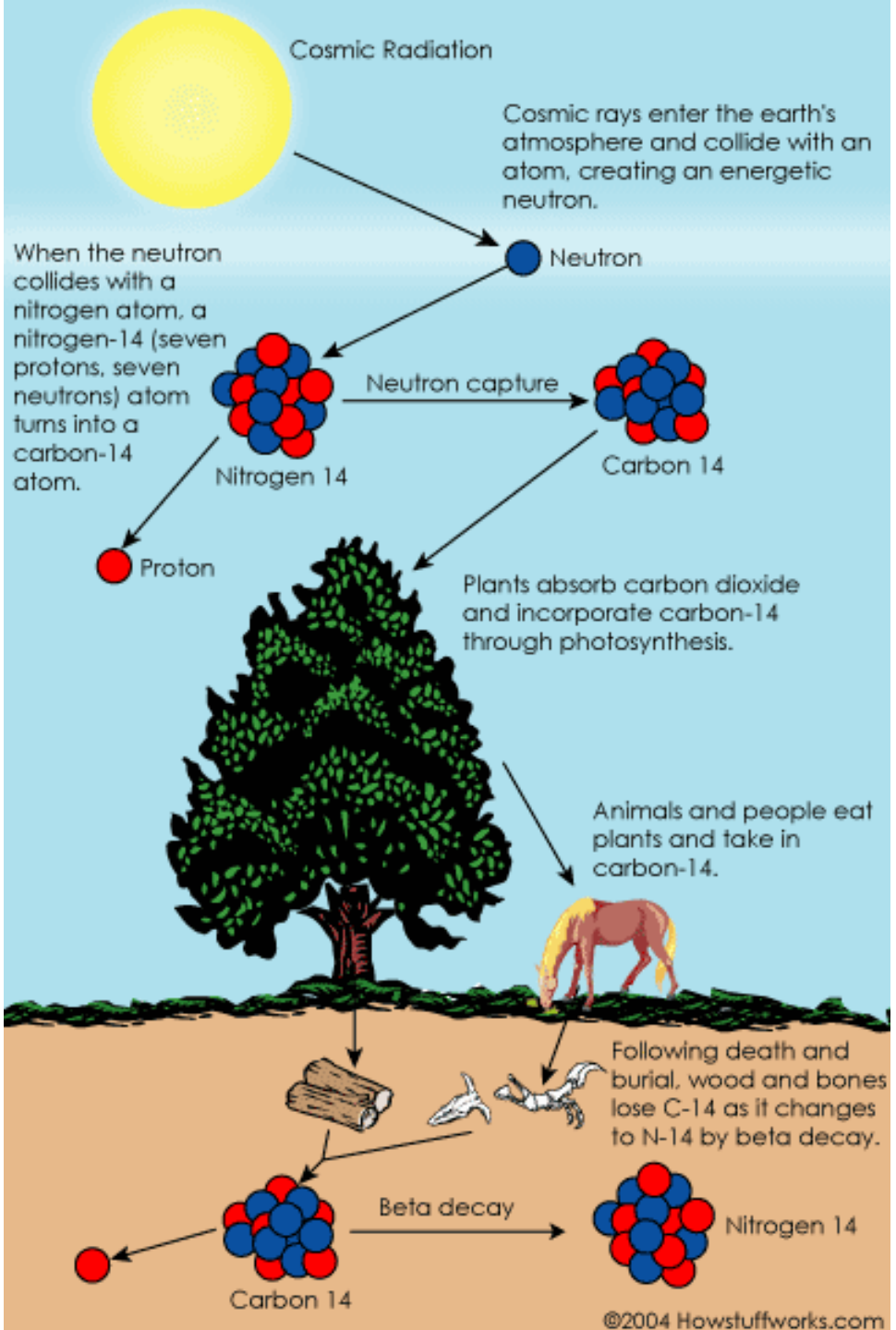
Can use radioactive isotopes to date objects
Radio dating …. nucleocosmochronology

Radiodating ^{14}C

Carbon has 6 protons
Nitrogen has 7 protons

$$n + {}^{14}\mathrm{N} \rightarrow p + {}^{14}\mathrm{C}$$

$${}^{14}\mathrm{C} \rightarrow \mathrm{e}^{-} + {}^{14}\mathrm{N}$$



^{14}C dating

- Carbon has two main isotopes ^{12}C and ^{14}C
- ^{14}C (6 protons + 8 neutrons) is unstable
  - half life of 5,746 years
- ^{12}C (6 protons +6 neutrons) is stable
  - it doesn't decay

$$N_{14}(t) = N_{14}(0)\, 2^{-t/5746\,\text{years}}$$

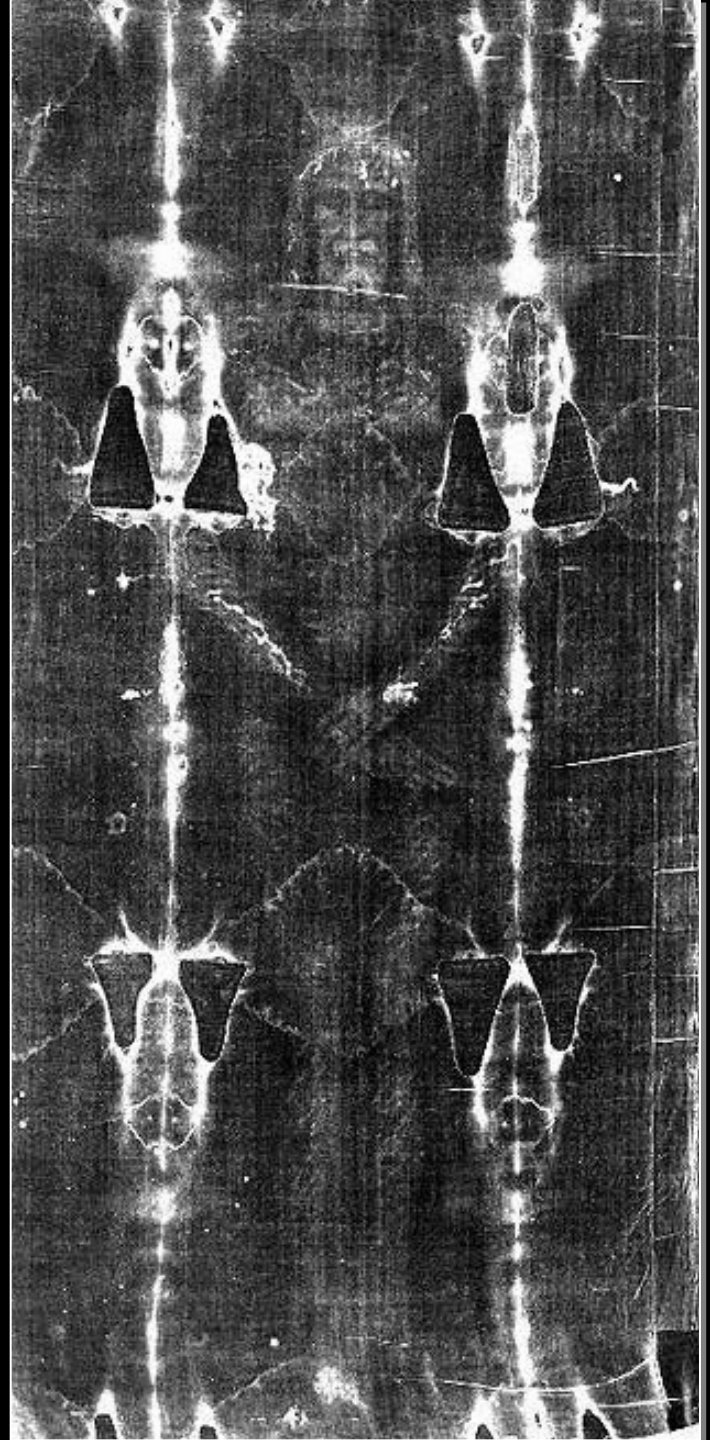
$$N_{12}(t) = N_{12}(0)$$

$$\frac{N_{14}}{N_{12}}(t) = \frac{N_{14}}{N_{12}}(0)\, 2^{-t/5746\ \text{years}}$$

Torino

il Duomo di Torino (1498)
la Cappella della Santa Sindone
e sullo sfondo la Mole Antonellian

Turin Cathedral,
Holy Shroud Chapel
and Mole Antonelliana



The Shroud of Turin


BILL ACOSTA
Flamingo
TO Fabulous
LAS VEGAS
NEVADA

Caesar's Palace

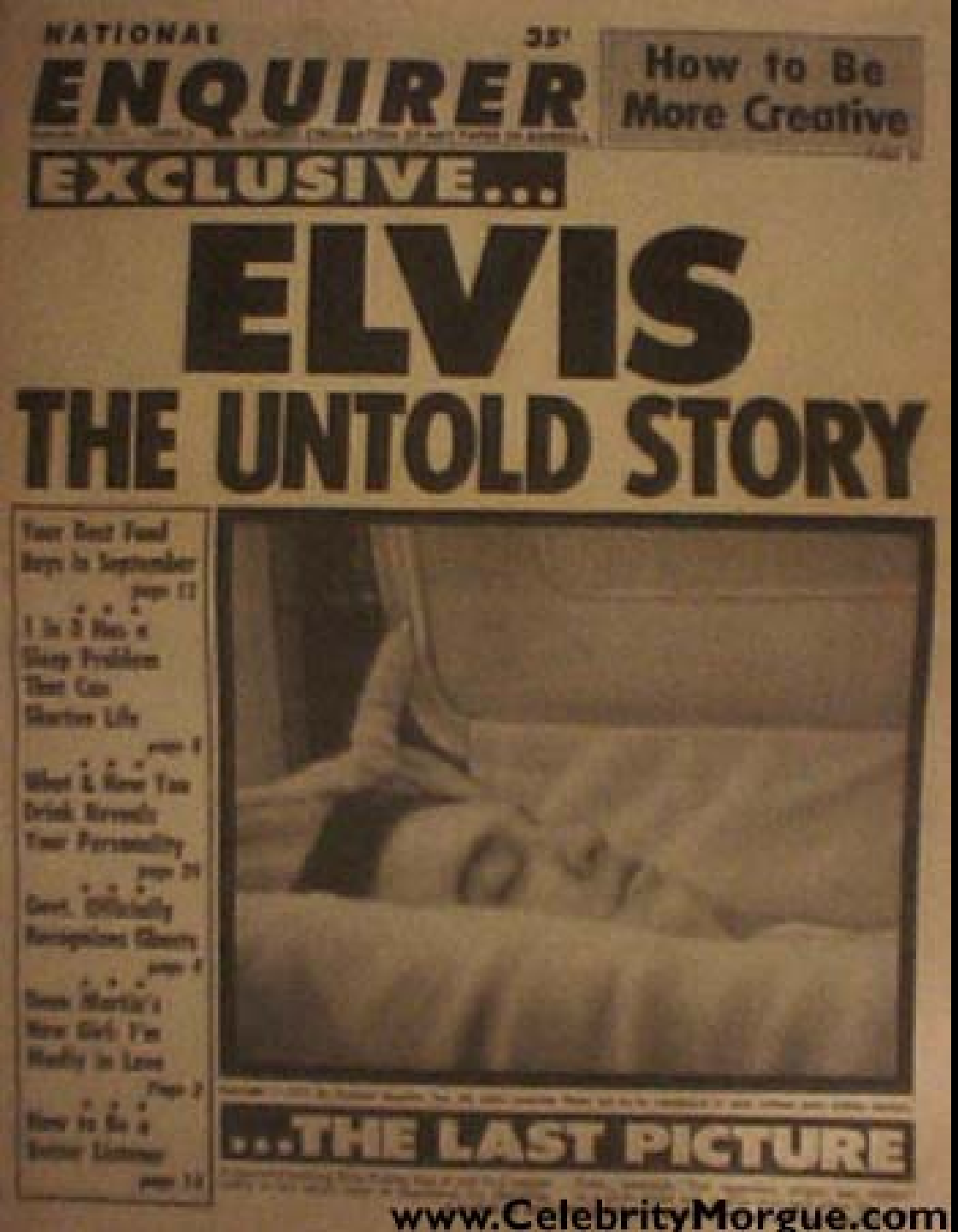
Shroud of Vegas

CSI: Hyde Park

Cosmological Scene Investigation

Task: Determine authenticity of Shroud of Vegas

- Re-enact scene of Elvis's (purported) death
- Examine evidence
- Use scientific tools (radiodating…not faith-based)



Death of Elvis